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The pathogen Myrtle Rust (*Puccinia psidii*) in the Northern Territory: First detection, new host and potential impacts

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Abstract

The plant pathogenic fungus Myrtle Rust (*Puccinia psidii*) was detected within the Northern Territory on Melville Island in May 2015, five years after its arrival in New South Wales. In July the rust was found on mainland Northern Territory on the outskirts of Darwin and in September in the Darwin suburbs. Four myrtaceous plant species were found infected by the rust including the indigenous shrub *Lithomyrtus retusa*, which represents a novel host for *P. psidii*. The mode of arrival and the ecological implications of the spread of Myrtle Rust infection across Top End vegetation and plant industries are discussed.

Introduction

Myrtle Rust affects plants of the Myrtaceae family which includes many well-known natives such as eucalypts (*Eucalyptus, Corymbia*), paperbarks (*Melaleuca*), bottle brush (*Melaleuca,* formerly *Callistemon*), tea tree (*Leptospermum*) and lilly pillies (*Syzygium*). Ten percent of Australia's flora belongs to the Myrtaceae and a considerable proportion of these plants may be vulnerable to Myrtle Rust infection.

Infection by Myrtle Rust typically causes distortion or loss of new growth and partial defoliation/dieback; thus it reduces photosynthetic capacity in susceptible plants and reduces reproductive capacity in some species if fruits are also infected. This fungal pathogen could have serious impacts on commercial and native plants, affecting plant nurseries, garden centres and forestry, tea tree and Australian native food industries.

Myrtle Rust taxonomy and biology

Rusts are plant diseases caused by fungal pathogens, specifically basidiomycete fungi of the order Pucciniales. *Puccinia psidii* is an exotic fungal pathogen of a complex of closely related species referred to as Myrtle Rust, Eucalyptus Rust or Guava Rust. It was first described from a specimen collected in 1884 from Guava (*Psidium guajava*) in South America (Winter 1884 cited in Glen *et al.* 2007). Myrtle Rust is now regarded as native to Central and South America (Ferreira 1983 cited in Carnegie *et al.* 2015, Glenn *et al.* 2007, Ramsfield *et al.* 2010). It has subsequently spread to the USA (Marlatt & Kimbrough

1979), across the Pacific to Hawaii (Uchida *et al.* 2006), Japan (Kawanishi *et al.* 2009), China (Zhuang and Wei 2011 cited in Carnegie *et al.* 2015) and Australia. Myrtle Rust has recently been recorded in South Africa (Roux *et al.* 2013) and also Indonesia (McTaggart 2015).

Native rusts do occur in Australia (on multiple plant families) but are rare on Myrtaceae with only two rusts indigenous to three host plants. Knowledge of the rust and its life cycle are important in understanding the impact of the organism in its environment. Rusts can exhibit complex life cycles with multiple spore types (vegetative as well as sexual) and alternative hosts. Myrtle Rust can, however, complete its life cycle on a single host, rapidly producing enormous numbers of readily dispersed infectious urediniospores via asexual means. Furthermore, Myrtle Rust sometimes produces teliospores which can recombine genetic material with compatible mating types, importantly yielding adaptive variation (Makinson 2012). A characteristic of rusts that makes them formidable plant pathogens is their ability to evolve rapidly under selective pressure.

When Myrtle Rust arrived in Australia it was thought to differ morphologically from the holotype of *P. psidii* by lacking teliospores. Australian material was placed in the genus *Uredo* which produces solely urediniospores, and was described as a new species, *Uredo rangelii* (Simpson *et al.* 2006). However, teliospores have since been found on Australian Myrtle Rust specimens and in concurrence with a lack of molecular differences *U. rangelii* is now synonymised as a biotype (a strain with differential physiological characteristics) of *P. psidii* and not recognised as a unique species (Carnegie & Cooper 2011).

Results from recent molecular analysis indicate that *P. psidii* specimens from Australia are closely related to those from Hawaii (Machado *et al.* 2015) and also those recently studied from Indonesia (McTaggart *et al.* 2015). More significantly, Australian *P. psidii* specimens appear to be genetically uniform and not undergoing sexual recombination, suggesting that only a single predominantly asexual biotype is currently present here. Introductions of novel strains of *P. psidii* would however increase the likelihood of mating compatibility leading to more genetic diversity in local Myrtle Rust populations.

Dispersal

Unlike many fungi that can survive on dead and decaying organic matter, rusts are obligate biotrophs dependent on living host tissue for reproduction and survival. Rusts produce huge numbers of spores for wind dispersal from one host to another (Brown & Hovmoller 2002). Rusts are renowned long-distance dispersers with, for example, one race of Wheat Stripe Rust spreading from Australia to New Zealand in two months and another race spreading from western Australia to eastern Australia within a year (Grgurinovic *et al.* 2006). Rust pathogens are in fact intercontinental travellers (Gregory 1963, Viljanen *et al.* 2002 cited in Brown & Hovmoller 2002).

Myrtle Rust produces vast numbers of tiny urediniospores which are highly suited to aerial dispersal over long distances. The spore's thick walls resist desiccation and their pigmentation resists ultraviolet radiation allowing them to survive high in the air column for long periods without degradation. Spore longevity is thought to be approximately 90 days (Glen *et al.* 2007) but would depend on ambient conditions.

Thus, vast production of spores and their ability to travel long distances enable the disease to spread rapidly. For example, *P. psidii* infecting Allspice in Jamaica covered an area of 5000 km^2 within one year (Smith 1935 in Glen *et al.* 2007) and in Hawaii the disease spread to all (but one) islands within nine months (Killgore and Hue 2005).

In addition to dispersal by wind, Myrtle Rust spores are spread by moving infected plant material including nursery stock or cut flowers. At times of movement, plants can appear asymptomatic as the infection may be dormant until conditions are conducive.

Rust spores are also dispersed by human-assisted or animal-assisted means. Spores are inadvertently transported attached to clothing, vehicles, machinery, tools and other equipment (Tommerup *et al.* 2003) that may come in close proximity to infected plants. Animals such as bees, bats and birds can transport rust spores if they contact infected plant parts during feeding and foraging. Native bees (*Tetragonula* spp.) have been observed harvesting rust spores (possibly due to the resemblance of bright orange spores and pollen) and are thus potentially implicated in transfer of the disease.

Detection in Australia

Myrtle Rust was first detected in Australia in April 2010 on the central coast of New South Wales in a cut flower nursery (Carnegie *et al.* 2010). Since this initial detection, it had spread to Queensland by late 2010 and to Victoria in 2011 and is now present across much of eastern New South Wales and Queensland. It has also been found in 2015 in northern Tasmania.

Detection in the Northern Territory

In May 2015, during a routine plant health inspection by Northern Australia Quarantine Strategy (NAQS), officers detected Myrtle Rust on Melville Island of the Tiwi Islands, Northern Territory. During the NAQS plant health survey Myrtle Rust was observed at four locations over the western part of Melville Island (Fig. 4) on three host species:

- cultivated Beach Cherry (*Eugenia reinwardtiana*) plants;
- native mature *Lithomyrtus retusa* shrubs (Figs 1, 2); and
- minor (light) infection on cultivated Weeping Ti-tree (*Leptospermum madidum*) (Fig. 3).

Fig. 1. *Lithomyrtus retusa* shrubs infected by Myrtle Rust (*Puccinia psidii*) on Melville Island, May 2015. (John Westaway)

Fig. 2. Foliage (left) and fruit (right) of *Lithomyrtus retusa* infected with Myrtle Rust on Melville Island, May 2015. (John Westaway)

Of 20 different myrtaceous species inspected on Melville Island in May only these three host species displayed symptoms, with the indigenous *Lithomyrtus retusa* most seriously affected, suggesting this species to be highly susceptible to Myrtle Rust infection.

Fig. 3. Foliage of cultivated Weeping Ti-tree (*Leptospermum madidum)* showing light infection with Myrtle Rust on Melville Island, May 2015. (John Westaway)

The Northern Territory Department of Primary Industry and Fisheries (DPIF) had been conducting surveillance for Myrtle Rust in Darwin plant nurseries since its arrival in Australia. Following the detection on Melville Island, surveillance was undertaken in nurseries and mainland properties associated with the Tiwi Islands but the rust was not found. Highly susceptible plants in Darwin, including *Eugenia reinwardtiana* and a stand of mature *Syzygium jambos*, were checked periodically by the author and found to be symptom free. It was thought the most likely pathway for introduction of the disease was via human agency with nearly all visitors to the Tiwi Islands transiting through Darwin. However an alternative pathway of cyclone-assisted wind dispersal was possible as category 4 Tropical Cyclone Lam passed from Queensland through the Gulf of Carpentaria and onto coastal Northern Territory during the February 2015 wet season, which could potentially have transported Myrtle Rust fungal spores to Melville Island.

Such an interstate dispersal event would not be without precedent as Sugarcane Smut *(Sporisorium scitamineum)* dispersed from Western Australia to Queensland on a particular weather event (Croft *et al.* 2008) and it is also likely that the fungal Grapevine Leaf Rust that appeared in Darwin in 2001 was a result of wind-born inoculum from Timor-Leste or Indonesia, where the disease is widespread (Daly & Tran-Nguyen 2008).

During a plant health survey of Garug Gunak Barlu National Park, Cobourg Peninsula, in June 2015, NAQS had an opportunity to investigate native and cultivated myrtaceous plant species for symptoms of Myrtle Rust infection. Eighteen different myrtaceous plant species were examined in the field at a range of locations over the eastern parts of Cobourg Peninsula and no evidence of Myrtle Rust infection was observed. Plants inspected included the three species found infected at Melville island – *Lithomyrtus retusa*, *Eugenia reinwardtiana* and *Leptospermum madidum* – the first two being highly susceptible hosts. Evidence of Myrtle Rust on Cobourg Peninsula would certainly have lent weight to the cyclone pathway hypothesis.

In July 2015, DPIF plant biosecurity officers and the author inspected local Darwin populations of *Lithomyrtus retusa*, the plant severely infected on Melville Island. The nearest populations are located at Berry Springs (Fig. 4) and these were found to be infected by Myrtle Rust, albeit more lightly than on Melville Island.

Myrtle Rust was subsequently detected on *Syzygium armstrongii* in a plant nursery in outer Darwin in September 2015. The infected plants were later destroyed. *Syzygium armstrongii*

Fig. 4. Locations where Myrtle Rust was found in 2015 on Melville Island, near Berry Springs and in Darwin.

Fig. 5. Cultivated *Eugenia reinwardtiana* shrubs infected with Myrtle Rust at the Jingili Water Gardens, September 2015. (John Westaway)

had previously been recorded infected by Myrtle Rust (Giblin and Carnegie 2014), but those host plants were presumably cultivated as this species is endemic to the Northern Territory (Northern Territory Herbarium 2015). Populations of *S. armstrongii* occurring in the wild may also be susceptible to infection by *P. psidii.*

Myrtle Rust was also found to have infected two cultivated Beach Cherry (*Eugenia reinwardtiana*) plants (Fig. 5) at Darwin's Jingili Water Gardens in late September 2015.

Potential Impacts

Myrtle Rust infects 'new growth', i.e. actively growing shoots and sometimes also buds and fruits (Fig. 2) of susceptible myrtaceous host plants resulting in foliage die-back, reduced photosynthetic and reproductive capacity and increased likelihood of secondary disease. Infection can even lead to tree mortality in some hosts (Carnegie *et al.* 2015). Potential impacts include economic loss for plant nursery industries growing rust-susceptible varieties of myrtaceous plants as Myrtaceae constitute an important component of native plant nursery stock. As mentioned above, Myrtle Rust has been detected on *Syzygium armstrongii* in a plant nursery situation.

There are some small-scale horticultural enterprises in the Northern Territory that may be vulnerable to Myrtle Rust, for example Guava (*Psidium guajava, P. cattleianum* var. *cattleianum*) crops and edible fruiting trees variously termed Rose/Water/Malay Apple or Jambu (*Syzygium aqueum, S. jambos, S. malaccense, S. samarangense*). Currently, Myrtle Rust has not been seen infecting these cultivated Guava or 'bush apple' hosts in the Northern Territory.

Monocultures of susceptible species are particularly vulnerable. There is potential for nursery Myrtaceae to be treated with appropriate fungicides but this is less feasible for commercial crops such as orchards and silvicultural plantations. For example, commercial bush-food plantations of Aniseed Myrtle (*Anetholea anisata*) and Lemon Myrtle (*Backhousia citriodora*) have been affected in New South Wales. Commercial

Guava and *Eucalyptus* plantations are affected in Brazil and the Pimento industry in the Caribbean was devastated by the Myrtle Rust.

Amenity plantings are likely to suffer a decline in aesthetic value as myrtaceous plantings experience dieback. This is potentially significant in Darwin and Palmerston where myrtaceous trees are commonly used in streetside amenity plantings.

Further to the direct commercial implications inferred above, there is potential for significant negative impact on economic and spiritual values held by Indigenous people of the Top End. Two examples are the importance of *Syzygium* fruit 'bush apples' as bush tucker and the spiritual importance of vegetation communities dominated by An-binik (*Allosyncarpia ternata*) in the western Arnhem region (Director of National Parks 2016).

Myrtaceae

The Myrtaceae is a large and diverse family of trees and shrubs distributed primarily in the southern hemisphere with considerable tropical representation. Although worldwide, the Myrtaceae is particularly significant ecologically in Australia as genera occur in 11 of the 13 major Australian plant formations (Specht 1981) and much of the Australian landscape is characterised by vegetation communities dominated structurally and/or floristically by myrtaceous plants (Pryor & Johnson 1981). On a continental scale, myrtaceous plants represent a high proportion of plant biomass in Australia, and are thus responsible for much of the plant gaseous exchange with the atmosphere and much of the nutrient recycling with soils – both critical environmental services.

The Myrtaceae is a key iconic plant family in Australia accounting for approximately 10% of the Australian flora, with more than 2250 species from amongst 95 genera (Australian National Botanic Gardens 2015a). The Myrtaceae contains the greatest number of species of any family of plants in Australia (Beadle 1981, Anonymous 1993) and more than half of the world's approximately 3000 species of myrtaceous plants are Australian (Australian National Botanic Gardens 2015b).

A considerable proportion of this diverse Australian Myrtaceae flora occurs in the relatively moist climatic zone east of the Great Dividing Range that has rainfall and temperature conditions suitable for survival of Myrtle Rust. *Puccinia psidii* has now been reported from more than 300 Australian Myrtaceae species from 57 genera. Two hundred and thirty species have been infected in the wild and a further 100 by inoculation only (Giblin & Carnegie 2014). The risk Myrtle Rust poses to the conservation of Australian flora is accentuated by the fact that more than

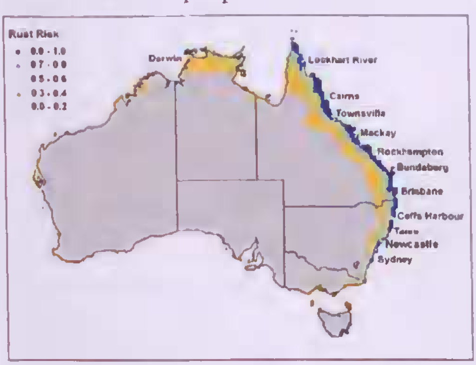

Fig. 6. Risk map for the spread of *Puccinia psidii*. (From Booth and Jovanovic 2012).

140 species of Myrtaceae are nationally threatened (*Environment Protection and Biodiversity Conservation Act 1999*; Glen *et al.* 2007). It is unknown how many of these threatened Myrtaceae are susceptible to Myrtle Rust infection but examples of known susceptible species include *Uromyrtus australis* and *Gossia gonoclada*, both listed as endangered under the *EPBC Act*.

Twenty-six genera of Myrtaceae are present in the Northern Territory. Many species of these genera occur in the semi-arid and arid zones that are not conducive to persistence of fungal rust infections in general. *Puccinia psidii* is unlikely to establish in arid regions due to its requirement for an extended period of leaf wetness (Ruiz *et al.* 1989 cited in Glen *et al.* 2007). The Top End of the Northern Territory can be defined as the area subject to a tropical monsoon climate (approximating the Territory north of 16 degrees latitude or receiving greater than 600 mm annual rainfall) and the climate here is more similar to the Australian east coast than to arid Northern Territory. Long-term impacts of Myrtle Rust on the natural environment of the Top End are not known but may be of grave concern as the disease inevitably spreads. A risk map for the spread of *P. psidii* (Fig. 6) developed by Booth and Jovanovic (2012) depicts the high-risk area of suitable climatic parameters to include the Top End of the Northern Territory.

Recent predictive climatic modelling (Kriticos *et al.* 2013) indicates a low ecoclimatic suitability for *P. psidii* in a limited area of eastern Arnhem Land and the Tiwi Islands (Fig. 7), though the authors caution uncertainty concerning the modelled risks in the tropics. These areas coincide with those predicted by the preliminary assessment of Booth *et al.* (2000) (Fig. 7).

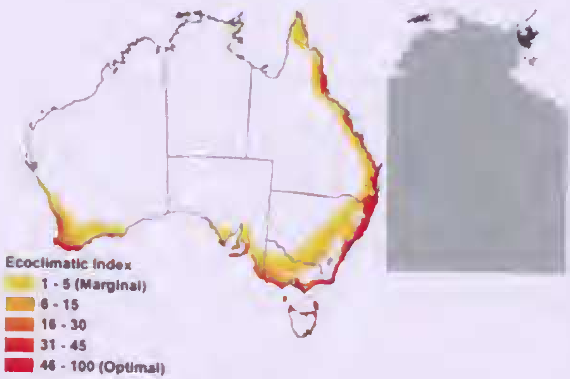

Fig. 7. Climate suitability map for *Puccinia psidii* in Australia as indicated by the CLIMEX Ecoclimatic Index (Kriticos *et al.* 2013) **left**, and risk areas identified by Booth *et al.* (2000) for the Northern Territory, **right**.

Fortunately the long extended dry season across the Top End of the Northern Territory (with no effective rainfall for 5 to 6 months) may help restrict the spread and impact of Myrtle Rust as it thrives best in humid mesic conditions. The Rust's requirement for leaf wetness (Zauza *et al.* 2010a) may limit its effectiveness in strongly seasonal environments although how this disease behaves in the monsoonal tropics is presently unknown. A plausible scenario may see Myrtle Rust radiating out from moist sheltered environments during the wet season and then contracting annually by the harsh conditions of the dry season back to refuges such as irrigated gardens, spring jungles and riparian vegetation. *Melaleuca* or *Syzygium* species in Top End riparian habitats may however present suitable host and microclimatic conditions for the pathogen to survive the dry season, permitting more or less permanent naturalisation of *P. psidii* in at least some parts of the Top End.

The number of Myrtaceae taxa present in the Top End of the Northern Territory can be calculated by subtracting the number of arid zone Myrtaceae (Albrecht *et al.* 2007) that do not extend their distributions into the Top End from the total Northern Territory Myrtaceae flora (Northern Territory Herbarium 2015; Department of Land Resource Management 2014). This yields some 151 Top End Myrtaceae taxa from 21 genera; with 66 species (of 14 genera) recorded for the Darwin region alone (Dunlop *et al.* 1995). In contrast to most rusts that infect only a few species, Myrtle Rust is remarkable for its wide host range. Under laboratory conditions about 90% of Australia Myrtaceae tested proved susceptible to Myrtle Rust to some degree (Morin *et al.* 2011). Given the diversity of species found to be susceptible to Myrtle Rust in Queensland (Giblin & Carnegie 2014, Queensland Government 2015), it seems reasonable to surmise that many/dozens of Top End species are also likely to be susceptible. Great variation has been observed in the level of susceptibility of myrtaceous plants to this rust ranging from relatively tolerant (e.g. many eucalypts) to extremely susceptible (e.g. *Eugenia reinwardtiana, Melaleuca quinquenervia*). Some species, e.g. *Rhodammia rubescens* and *Rhodomyrtus psidioides*, are impacted to the extent that many individuals die (Carnegie *et al.* 2015). Most susceptible species however are not killed but their reduced fitness and health are likely to affect their recruitment capacity. Susceptibility is also highly variable even among individuals of the same species (Zuaza *et al.* 2010b; Carnegie *et al.* 2015).

Many widespread common Myrtaceae species of the Top End (e.g. *Eucalyptus tetrodonta, Eucalyptus miniata*) as yet show no signs of infection and hopefully this suggests a level of tolerance, supported by the observation that mature eucalypts in eastern Australia, where Myrtle Rust has been established for longer, appear resistant to the disease. However as most Australian Myrtaceae are naive to rust disease they may yet prove to be susceptible, as pathogens are often more virulent on naive hosts (Glen *et al.* 2007). There is possibly a delay time frame before such species become susceptible, perhaps related to Rust strain (biotype), local inoculum loads and mutations rates.

Lithomyrtus retusa, the new host record for Myrtle Rust, appears to be especially susceptible based on observations that nearly all individuals (n=100s) inspected on Melville Island were infected (with most being severely infected) (Figs 1–3) whilst all other Myrtaceae (e.g. *Eucalyptus, Corymbia, Melaleuca, Lophostemon, Calytrix*) in close proximity showed no symptoms. The genus *Lithomyrtus* has its evolutionary centre in the Northern Territory with all but two of the ten species

Fig. 8. *Lithomyrtus retusa* collections at Australian herbaria. (Map courtesy of AVH)

occurring here. *Lithomyrtus retusa* is a widespread species across northern Australia (Fig. 8).

By contrast, seven of the other eight *Lithomyrtus* species that occur in the Northern Territory are endemic to the Northern Territory including the fire sensitive *Lithomyrtus linariifolia* which occurs amongst sandstone outcrops on the western Arnhem Land Plateau. Applying IUCN conservation criteria *L. linariifolia* is listed under the *Territory Parks and Wildlife Conservation Act 2000* as 'Vulnerable' to inappropriate fire regimes on account of its obligate seeding regeneration method and also vulnerable to stochastic events due to its small population size (estimated at <1000 mature individuals). It is not known whether *L. linariifolia* is susceptible to Myrtle Rust. The related *L. obtusa* that occurs in coastal Queensland is reported as being susceptible (Giblin & Carnegie 2014) but conspecific status does not appear to confer susceptibility as the diverse list of susceptible versus tolerant Myrtaceae indicates (see Queensland host list, Queensland Government 2015).

Although *L. linariifolia* is the only threatened Myrtaceae species in the Top End there are several restricted range Myrtaceae of conservation value that may be susceptible to Myrtle Rust, including the iconic Arnhem Land monsoon forest dominant tree *Allosyncarpia ternata. Allosyncarpia* is taxonomically significant as a monospecific genus and *A. ternata* is a keystone monsoon forest plant endemic to the specialised geology of the sandstone plateau in western Arnhem Land. Although *A. ternata* is locally common in sheltered or less fire prone sites on the plateau, its distribution globally is a very limited area. Myrtle Rust has not been found on *A. ternata* in the wild but the species has been infected in a deliberate inoculation test by CSIRO (Giblin & Carnegie 2014). If *Allosyncarpia* trees were susceptible, potential impacts may include reduced recruitment and vigour, canopy loss and marginal attrition of the forest community which could expose this Arnhem Land monsoon ecosystem to further fire and weed incursion.

Calytrix is another Myrtaceae genus with many endemic or restricted range species in the Top End. There are six *Calytrix* species (*C. decussata, C. faucicola, C. inopinata, C. miniana, C. rupestris* and *C. surdiviperana*) endemic to the Arnhem Plateau Sandstone Shrubland Complex ecological community (Department of the Environment 2015a), with all but the first two being listed with a conservation status of 'Near Threatened'. It is unknown whether any of these endemic plants are susceptible to Myrtle Rust. A single *Calytrix* species, *C. tetragona* from eastern Australia, has tested positive to *P. psidii* but only by inoculation test, not in the wild. The reduced leaf surface area and sclerophyllous nature of *Calytrix* may confer some anatomical resistance to infection.

A further nine Top End Myrtaceae – *Eucalyptus koolpinensis, Kunzea* sp. Keep River, *Melaleuca stipitata, M. triumphalis, Ochrosperma sulcatum, Stenostegia congesta, Asteromyrtus lysicephala, Syzygium claviflorum* and *S. hemilamprum* (the first six listed being Northern Territory endemics) are all considered of conservation concern and listed as "Near

Threatened" in the Northern Territory (Northern Territory Herbarium 2015). It is not known whether or not these species are susceptible to infection by Myrtle Rust.

Rock Myrtle (*Petraeomyrtus punicea*) is another key endemic Myrtaceae species of the threatened Arnhem Plateau Sandstone Shrubland Complex ecological community (Department of the Environment 2015b) and its susceptibility to Myrtle Rust is also unknown.

Vast tracks of the Top End landscape support vegetation comprised of paperbark trees of the Myrtaceae genus *Melaleuca*, sometimes occurring as monospecific and/or dense stands. There are seven *Melaleuca* species in the Top End that form extensive vegetation communities, typically on poorly drained or seasonally inundated soils with *Melaleuca leucadendra* and *M. cajuputi* amongst the tallest and best formed tree species in the Northern Territory (Dunlop *et al.* 1995)

Melaleuca viridiflora, *M. cajuputi* and *M. leucadendra* are all of high ecological significance in the Northern Territory as significant character species of several swamp forest, wetland and riparian vegetation communities across the Top End. They could be regarded as keystone species for these communities due to their provision of nectar, pollen, foraging and sheltering substrates and other resources for wildlife such as birds and including migratory species. On account of their community dominance across broad geographic ranges, these *Melaleuca* species also contribute substantially to the ecological services of water regulation and carbon sequestration. As *M. leucadendra* is particularly dependent on perennial water sources its potential demise due to Myrtle Rust may have negative hydrological and biodiversity repercussions in sensitive riparian habitats. *Syzygium armstrongii* is another important Myrtaceae tree of Top End riparian habitats and this Northern Territory endemic species has recently been observed infected with Myrtle Rust in a nursery situation.

Myrtle Rust has been recorded in New South Wales and Queensland on *M. viridiflora* and *M. leucadendra,* both of which are rated as 'highly susceptible', and also on the closely related Broad-leaved Paperbark (*Melaleuca quinquenervia*) which is rated as 'extremely susceptible' (Queensland Government 2015). Myrtle Rust severely damaged naturalised (introduced) *M. quinquenervia* in Florida in 1977 (Carnegie & Lidbetter 2012) and has been reported to impact on growth rate and tree structure in eastern Australia (Makinson 2014). *Melaleuca viridiflora* is an integral component of diverse tropical lowland environments across northern Australia. If indigenous populations of *M. viridiflora* were to succumb to the effects of this pathogen then there would likely be significant detrimental ecological flow-on effects depending on the degree to which this species is impacted. Even if individual plants are not killed, reduced plant health fitness means less nectar production. Furthermore, their reproductive capacity is likely to be impaired, resulting in lower recruitment and perhaps a slow demise of this significant vegetation community with unknown but likely deleterious implications for its dependant wildlife.

Eucalypts (*Eucalyptus, Corymbia and Angophora*) constitute the structural and/or floristic dominant tree species of much of non-arid Australia. Nearly 80 eucalypts (approx. 10% of total) are known to be susceptible to Myrtle Rust though most of these records are from laboratory inoculation tests rather than field observations (Giblin and Carnegie 2014). Furthermore, most mature eucalypts show some resistance or have only a low level of susceptibility. It appears that the vital life stages of seedlings and saplings, as well as epicormic and coppice growth, are most susceptible to Myrtle Rust infection. This is significant ecologically in Australia for post-fire regeneration and cohort-recruiting species in native ecosystems. Some of the susceptible eucalypts include important forestry species with the major impact for native forestry likely to be on succession, as regenerating seedlings are most vulnerable (Makinson 2014).

Across the Top End and perhaps indeed northern Australia, Darwin Stringybark (*Eucalyptus tetrodonta*) and Darwin Woolybutt (*Eucalyptus miniata*) are probably the most prevalent and widespread tree species. It is not understood if either of these two species are susceptible to infection by Myrtle Rust and if so to what degree infected plants may be impacted. Testing in eucalypts indicates there is substantial variation in susceptibility within the same species and between plants from different areas (Zuaza *et al.* 2010b).

Ecological interactions

There is likely to be interaction at the plant community level between the pathogen, the plant host and abiotic factors such as climate and fire. The impacts of Myrtle Rust may be most significant in situations where host plants are already stressed due to climatic conditions such as drought, fire regimes, competition from weeds and other factors that have reduced the resilience of the native vegetation communities. Myrtle Rust's greatest impact may be on plant community succession. If Myrtle Rust hampers regeneration of key or dominant Myrtaceae species thus impeding their ability to compete, there is potential for major changes in plant community composition at the landscape scale. Such changes would spell habitat loss for native flora and wildlife amounting to fundamental alteration of Australia's ecology. Poor recruitment and succession resulting in canopy decline may also increase fire impacts and promote invasion of weeds into light or canopy gaps. Furthermore, abiotic consequences such as soil erosion and reduced water retention and quality may be exacerbated.

Depending on Rust strain, degree of virulence, environmental conditions and development of tolerance, this disease has the potential to alter the composition and function of forest, woodland, heath and wetland ecosystems. The extended severe dry season conditions typical across the Top End are however not conducive to the prospering of fungal rust pathogens. Top End temperatures may not always suit Myrtle Rust as spore longevity is apparently diminished at temperatures greater than 30°C (Glen *et al.* 2007) and spore germination rates reduce in overnight temperatures greater than 20°C (Kriticos *et al.* 2013).

Susceptibility and impact on host plants may vary into the future as climatic parameters such as rainfall seasonality change, possibly making some areas more favourable to Myrtle Rust and others less so. The potential for greater impacts may arise if the genetic diversity of the pathogen increases through recombination with novel strains. A genetic/evolutionary 'arms race' may ensue between plant hosts developing tolerance and the fungal pathogen evolving to more virulent strains. Due to the relatively rapid reproductive cycle of fungi compared to that of long-lived perennial vascular plants, the odds favour the pathogen.

Myrtle Rust cannot be eradicated and will continue to spread, as the fungus produces incalculable numbers of spores that disperse readily via wind, animals and human activity. As there is no practical way to manage the airborne spread of spores, land managers may have to adapt their management practices where possible, for example by addressing other/concomitant pressures such as fire and weeds to alleviate overall impacts. Land managers may be able to utilise management tools such as fire to assist with protection of vulnerable high conservation value vegetation.

Though we cannot eliminate Myrtle Rust from northern Australia, we can slow down its spread, manage its impacts and undertake research to discover its full host range whilst seeking longer term solutions. Maintenance and strengthening of quarantine and biosecurity practices to avoid new genetic strains of Myrtle Rust arriving in Australia will help in limiting the pathogens impacts. The Northern Territory Department of Primary Industry and Fisheries has a website with information about Myrtle Rust, and it makes the following recommendations regarding what the public can do to help reduce the spread of Myrtle Rust in the Northern Territory:

- avoid importing Myrtaceae plants from New South Wales and Queensland;
- if bringing plants in from New South Wales and Queensland, make sure they have been treated with an approved fungicide; and
- practise good hygiene when working with plants. Cleaning equipment such as secateurs after use will help reduce the spread of other plant diseases as well.

Territory residents and nursery growers are asked to report suspected infected plants by contacting the Exotic Plant Pest Hotline on 1800 084 881. It is also important to avoid plant movements into uninfected areas. If people suspect they have come into contact with Myrtle Rust then careful decontamination of clothing and equipment is required.

Makinson (2012) provides detailed advice on appropriate responses to the threat of Myrtle Rust spread including vulnerable asset identification, risk assessment, precautions, decontamination methods, hygiene protocols and options for risk reduction.

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